

Flow Rate of Corn Through Orifices as Affected by Moisture Content

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ABSTRACT

THE flow rate of corn through round and square horizontal orifices was evaluated. Moisture content of the test corn lots, which ranged from 12.3 to 22.3% (w.b.), had a significant effect on both volume and mass flow rates. For the same size of orifice, the flow rate of corn increased as the moisture content decreased. An equation expressing volume flow rate of corn as a function of orifice size was obtained. The velocity of grain through an orifice increased almost linearly as the orifice size increased at given moisture contents.

INTRODUCTION

Information on the flow rate of grain through an opening in a bin, hopper, or other grain handling system is necessary for properly sizing the opening in order to control grain flow to and from storage and holding bins.

To estimate the rate of grain flow through horizontal openings, Stahl (1950) indicated that grain flow was proportional to cube of the diameter, or the product of length and width of an opening.

Experimental curves expressing the relationship between the flow rate of wheat and the size of an opening were reported by Whited (1901).

The flow of dried shelled corn through small openings has been tested by Ewalt and Buelow (1963). They reported that the flow rate can be estimated from the following equations:

$$Q = AD^k \dots\dots\dots [1]$$

$$Q = BL^{k1} W^{k2} \dots\dots\dots [2]$$

where Q = volume flow rate
 D = diameter of opening
 L = length of opening
 W = width of opening
 $A, B, k, k1, \text{ and } k2$ are constants

Ewalt and Buelow's experiment data were limited to openings of 13 cm or smaller. Openings larger than 13 cm in grain handling systems for grain flow control are common; however, information on the flow of corn through these larger openings is very limited.

The objectives of this study were to determine the flow rate of shelled corn through round and square horizontal

openings, and to evaluate the effect of moisture content on the flow rate.

MATERIALS AND EQUIPMENT

Corn (Hybrid No. 3020, Ferry Morse Co.) used in these experiments was harvested in 1982. Moisture contents of corn lots tested were 12.3, 15.1, 19.1 and 22.3% (w.b.). Test lots of corn with moisture contents of 15.1, 19.1 and 22.3% were freshly field harvested without drying. The test lot of corn with 12.3% moisture was obtained by drying high moisture corn in a grain bin.

Two sets of orifices were used in these experiments. One set had openings of 12.7, 15.2, 17.8, 20.3, 22.9, and 25.4 cm in diameter, and another set had openings of 12.7, 15.2, 17.8, 20.3, and 22.9 cm square. Orifice sizes of 17.8 and 22.9 cm round and 17.8 cm square were added to the sets in a later stage of testing and were used only for corn with moisture contents of 15.1 and 12.3%. Each corn lot weighed 7.6 t which filled the holding bin to a depth of about 2.2 m (Fig. 1). For each moisture content, the same corn lot was used for both sets of orifices.

PROCEDURE

Before a given test, a desired amount of grain was transferred to a holding bin by means of a bucket elevator. During the transfer, grain samples were taken by an automatic sampler (Carter-Day, CHCI 132) for an analysis of moisture content, broken corn and foreign material (BCFM), test weight, and size classification. Test weight and moisture content were determined by a grain analysis computer (Model GAC II DICKEY-john Corporation, Auburn, IL). BCFM was determined with a

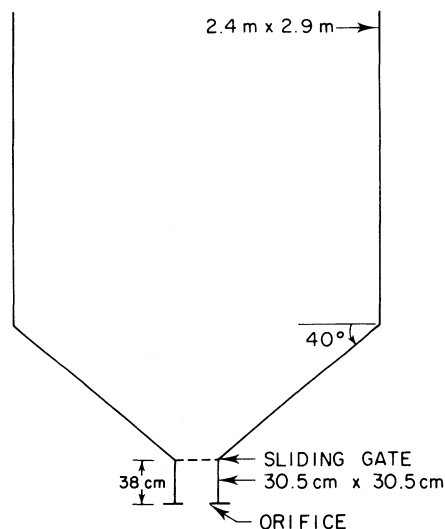


Fig. 1—Schematic of holding bin.

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4.8-mm round-hole sieve. Particles which passed through the sieve and all material other than corn which remained on top of the sieve were considered BCFM. Size classification was determined by a corn grader (Model 22C, Universal Hoist and Manufacturing Co.).

The holding bin (Fig. 1) was 2.4 m x 2.9 m x 7.6 m high with a hopper-bottom sloping toward the central opening at an angle of 40 deg from horizontal. The opening was 30.5 cm square. A 38-cm long vertical section of 30.5 cm square spout with a sliding gate was attached to the opening. The test orifice was installed at the bottom of the slide gate spout. A test was started when the sliding gate was opened to permit grain to flow through the test orifice to a receiving bin. A stopwatch was used to measure the length of time required for the holding bin to empty. The mass flow rate of grain was determined from the data on grain lot weight and flowing time. The volume flow rate was obtained from the values of mass flow rate and test weight.

RESULTS AND DISCUSSION

Moisture content, test weight, and BCFM of test corn lots are given in Table 1. The test weight of corn was significantly affected by its moisture content. The test weight increased as the moisture content decreased.

Table 2 shows the distributions of size and shape of test corn. Size classification was determined only for corn with moisture content of 12.3%. Test corn lot consisted of about an equal amount of large and small grain by size classification, and of about 83% of flat grain and 13% of round grain by shape classification.

For a given moisture content of corn, two flow rate tests were conducted for each size of orifice. Results were statistically similar for the two replicated tests. The standard errors of a treatment mean were 0.33 m³/h for round orifices and 1.02 m³/h for square orifices.

Volume Flow Rate

The curves plotted on log-log scale paper of volume flow rate vs orifices diameter or the length of orifice side were nearly linear for all tests. Thus the flow rate can be expressed as a function of orifice size in the following form:

$$Q = C_1 U^{C_2} \dots \dots \dots [3]$$

TABLE 1. MOISTURE CONTENT, TEST WEIGHT, AND BCFM OF TEST CORN LOTS.

Moisture content, % w.b.	Test weight, kg/m ³ (lb/bu)		BCFM, %
12.3	793	(61.6)	3.4
15.1	722	(56.1)	3.9
19.1	707	(54.9)	2.3
22.3	685	(53.2)	1.5

TABLE 2. DISTRIBUTION OF SIZE AND SHAPE OF TEST CORN

Large round	Large flat	Small round	Small flat	Residue †
W* > 8.3 mm		6.7 mm < W < 8.3 mm		W < 6.7 mm
T‡ > 5.9 mm		T > 5.2 mm		T < 5.2 mm
4.1%	44.1%	9.1%	38.6%	4.1%

*W: width of corn kernel

†Residue: Consists of small grain, broken corn, and fines

‡T: thickness of corn kernel

TABLE 3. COEFFICIENTS OF THE EQUATION* EXPRESSING VOLUME FLOW RATE OF CORN AS A FUNCTION OF ORIFICE SIZE.

Moisture content, % w.b.	Coefficients			
	Round orifice		Square orifice	
	C1	C2	C1	C2
12.3	0.0254	2.761	0.0271	2.835
15.1	0.0263	2.743	0.0284	2.812
19.1	0.0348	2.645	0.0367	2.721
22.3	0.0412	2.595	0.0566	2.571

* $Q = C_1 U^{C_2}$

where

Q = volume flow rate, m³/h

U = orifice size (diameter or side length), cm

C1 and C2 are coefficients.

Volume flow rate was chosen instead of mass flow rate to be the parameter expressed as a function of orifice size, because an orifice has direct effect or control over volume flow rate rather than mass flow rate.

Coefficients C1 and C2 for corn at four different moisture contents were obtained by regression analysis using experiment data, and are given in Table 3. The correlation coefficients for the regression were 0.98 or higher and the standard error of estimate ranged from 2.0 to 5.6 m³/h. Fig. 2 shows the flow rates of various moisture contents of corn through round orifices with an initial head of 2.2 m. The flow rates for the 13 and 25 cm orifices were about 30 and 180 m³/h, respectively. For orifices smaller than 20 cm in diameter, the difference in flow rate was very small between corn with different moisture contents. For orifices larger than 20 cm, the flow rate was affected by moisture content. For the same size of orifice the flow rate increased as the moisture content decreased; the difference, however, was small between corn with moisture contents of 19.1 and 22.3%.

Flow characteristics of corn through square orifices (Fig. 3) were similar to that of corn through round orifices. For the same size of orifice the flow rate increased as the moisture content decreased for orifices larger than 18 cm square, and the difference in flow rate was larger between different moisture contents of corn as the orifice size increased. For orifice smaller than 18 cm square, the difference in flow rate was small between corn with different moisture contents.

For an orifice size of 12.7 cm square, a flow rate of 41.4 m³/h for corn with 11.3% w.b. moisture content was obtained by Ewalt and Buelow (1963), and of 36.5

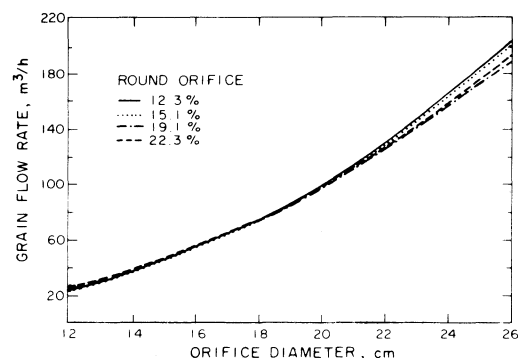


Fig. 2—Volume flow rate of various moisture contents of corn through round orifices with an initial head of 2.2 m.

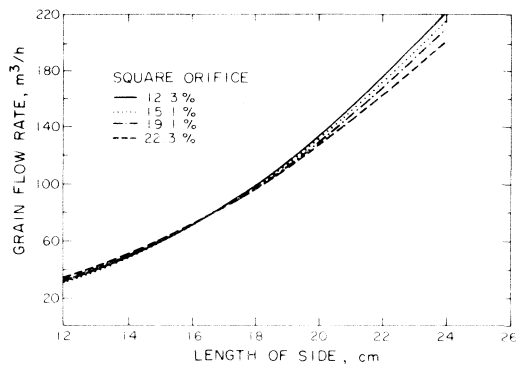


Fig. 3—Volume flow rate of various moisture contents of corn through square orifices with an initial head of 2.2 m.

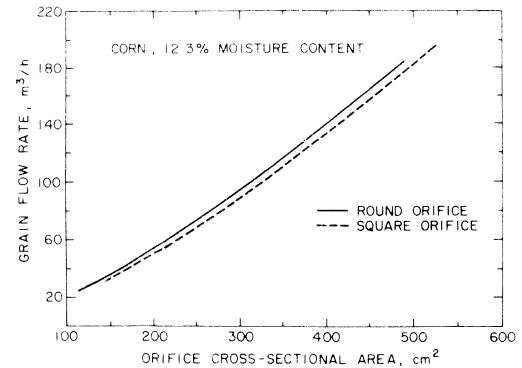


Fig. 4—Relationship between volume flow rate and area of round and square orifices for corn with an initial head of 2.2 m.

m³/h for corn with 12.3% w.b. moisture content was obtained in this study.

To estimate the flow rate of corn at any moisture content within the moisture range tested, coefficients C1 and C2 in equation [3] can be expressed as a function of moisture content:

$$C1 = a1 + a2 M + a3 M^2 \dots\dots\dots [4]$$

$$C2 = b1 + b2 M + b3 M^2 \dots\dots\dots [5]$$

where M = moisture content, % w.b.
 $a1, a2, a3, b1, b2,$ and $b3$ are regression coefficients (Table 4).

The correlation coefficients for both equations [4] and [5] were 0.99. The standard errors of estimate for equations [4] and [5] were 0.0015 and 0.021, respectively, for round orifices and were 0.0018 and 0.007, respectively, for square orifices.

Fig. 4 shows the relationship between the volume flow rate and the area of round and square orifices. For the same size of orifice area, the flow rate of corn through a square orifice was about 5% less than that of corn through a round orifice. This small reduction in flow rate for the square orifice was probably due to the fact that a small area making up the edge of the square corners was not effectively used by the grain kernels as a flowing path.

Mass Flow Rate

Mass flow rates of corn through round and square orifices with an initial head of 2.2 m are shown in Figs. 5 and 6, respectively. For the same size of orifice, the mass flow rate of corn increased as the moisture content decreased. The difference in mass flow rate was larger

than the difference in volume flow rate between different levels of moisture content. This was expected because the test weight of low moisture corn was higher than that of high moisture corn.

Grain velocity

Assuming that the bulk density of corn while passing through the orifice is equal to its test weight, the grain velocity through the orifice can be calculated from the volume flow rate and the area of the orifice. The velocities of corn through various sizes of orifice with an initial head of 2.2 m are shown in Figs. 7 and 8. Grain velocity increased almost linearly as the orifice size increased. The slope of the velocity curve increased as the moisture content decreased.

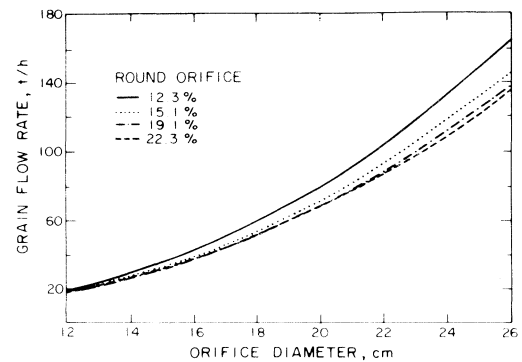


Fig. 5—Mass flow rate of various moisture contents of corn through round orifices with an initial head of 2.2 m.

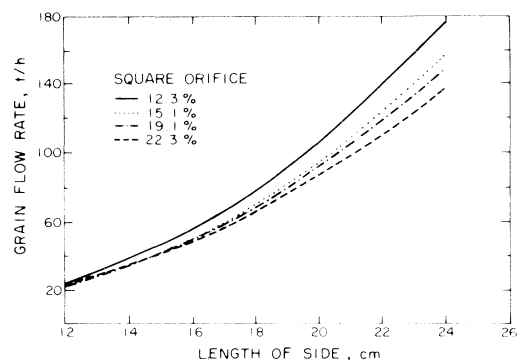


Fig. 6—Mass flow rate of various moisture contents of corn through square orifices with an initial head of 2.2 m.

TABLE 4. COEFFICIENTS IN EQUATIONS [4] AND [5]*

Coefficient	Round orifice	Square orifice
a1	3.51E-2	1.08E-1
a2	- 2.20E-3	- 1.17E-2
a3	1.12E-4	4.21E-4
b1	2.84	2.39
b2	1.07E-3	7.07E-2
b3	- 5.43E-4	- 2.80E-3

* $C1 = a1 + a2 M + a3 M^2$

$C2 = b1 + b2 M + b3 M^2$

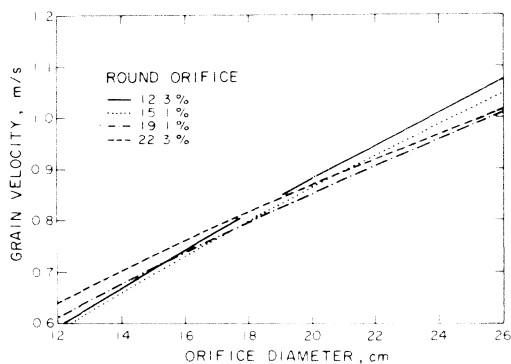


Fig. 7—Velocity of various moisture contents of corn through round orifices with an initial head of 2.2 m.

It should be noted that for a given size of orifice, the flow rate of corn may vary with the variety due to the differences in kernel size and geometry. The depth of grain (head) over the orifice may have some effect on the flow rate which is not determined.

SUMMARY AND CONCLUSION

Experiments were conducted to determine the flow rate of shelled corn through various sizes of round and square orifices and to evaluate the effect of moisture content on the flow rate. Moisture contents of test corn lots ranged from 12.3 to 22.3%. The sizes of orifices tested ranged from 12.7 to 25.4 cm in diameter and from 12.7 to 22.9 cm square. The initial grain depth in the holding bin was about 2.2 m.

The relationships between the volume flow rate of corn and the orifice diameter or the length of orifice were log-linear. Thus the flow rate of corn can be expressed as a

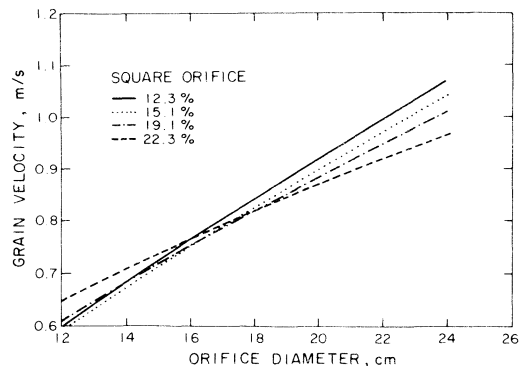


Fig. 8—Velocity of various moisture contents of corn through square orifices with an initial head of 2.2 m.

function of orifice size as given in equation [3].

In general, the effect of moisture content on the grain flow rate was small for orifices smaller than 20 cm. For orifices larger than 20 cm the flow rate increased as the moisture content decreased.

The velocity of grain through an orifice increased almost linearly as the orifice size increased. The rate of increase in velocity with orifice size was greater for low moisture corn than for high moisture corn.

References

1. Ewalt, D. J. and F. H. Buelow. 1963. Flow of shelled corn through orifices in bin wall. Mich. Agr. Expt. Sta. Quart. Bul. 46:92-102.
2. Stahl, B. M. 1950. Grain bin requirements. USDA Circular No. 835 (Based on data in Engineering Data on Grain Storage, Agricultural Engineering Data 1:1-11, 1948.)
3. Whited, Willis, 1901. The flow of semi-fluids through orifices. Proc. Eng. Soc. Western Penna. 17:113-129. ASAE Data: ASAE D274.